International Timing and Sync Forum
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Network Timing with DOCSIS

For Mobile Backhaul

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DTP - DOCSIS Time Protocol

Market Drivers
- Mobile Backhaul over DOCSIS

Today's cable operators are tomorrow's mobile operators

CBRS Auction Sept 2020

Welcome 7 new mobile companies who are also cable companies

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Source: FCC Website

Ranking	Bidder	Bidding Credit Type	Number of Licenses Won	Number of Counties	Gross Payment
1	Verizon Wireless		557	157	$ 1,893,791,991
2	Wetterhorn Wireless L.L.C. (Dish)		5,492	3,128	$ 912,939,410
3	Spectrum Wireless Holdings (Charter)		210	106	$ 464,251,209
4	XF Wireless Investment, LL (Comcast)		830	306	$ 458,725,900
5	Cox Communications, Inc		470	173	$ 212,805,412
6	Southern California Edison		20	15	$ 118,951,433
7	Windstream Services LLC,00		1,014	296	$ 38,534,863
8	AMG Technology Investment0	rural - 15%	1,072	491	$ 33,517,353
9	Mediacom LLC		576	178	$ 29,478,887
10	SEAD, L.L.C.		7	2	$ 25,274,477
11	San Diego Gas and Electric		3	2	$ 21,273,340
12	SAL Spectrum, LLC		1,569	590	$ 20,396,530
13	Puerto Rico Telephone		231	78	$ 18,887,528
14	Alabama Power Company		271	103	$ 18,878,280
15	VTX Communications, LLC001	rural - 15%	112	32	$ 18,086,192
16	NE Colorado Cellular, Inc.	rural - 15%	558	143	$ 17,749,727
17	Shenandoah Cable		262	74	$ 16,118,381
18	United States Cellular		243	80	$ 13,538,232
19	W.A.T.C.H. TV Company	rural - 15%	517	193	$ 12,872,997
20	Highland Opportunities, LL	small - 25%	180	82	$ 11,304,475
21	Aeronet Wireless Broadband	small - 25%	224	70	$ 11,213,720
22	Cable One, Inc.		547	175	$ 10,544,441
23	Hawaiian Electric Company,		10	4	$ 9,495,400
24	Actel, LLC		265	136	$ 9,060,243
25	Midcontinent (Midco)		269	75	$ 8,842,319

Most Cable Operators are Mobile Operators

Region	Cable Operators		
USA	GCI	MNO	
	Altice, Charter, Comcast, Cox		MVNO
Canada	Eastlink, Rogers, Shaw, Videotron	MNO	
Latin America	Telecom Argentina, Claro Brazil, Liberty Latin America	MNO	
Europe	Telenet (Belgium), TDC Net (Denmark), SFR (France), Vodafone (Germany), VodafoneZiggo (Netherlands), Telenor (Norway), NOS (Portugal), Telia (Nordic/Baltic), Tele2 (Nordic/Baltic), Virgin Media+Telefonica/O2 (UK)	MNO	
	VirginMedia (UK), Cablecom, UPC Poland, UPC Switzerland		MVNO

- Over half of the CableLabs' 63 members are already MNO or MVNO
- The third largest cable company is Vodafone.

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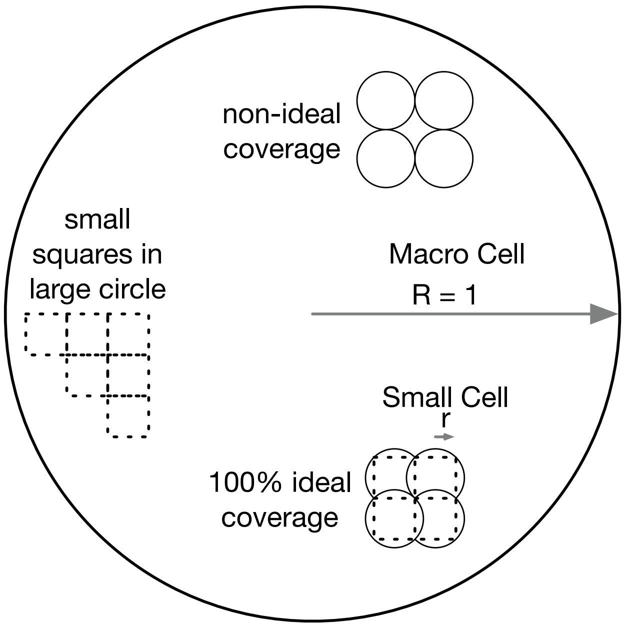
The Coming Explosion of 5G Small Cells



$$\# \, radios = \frac{\pi}{2}\left(\frac{R}{r}\right)^2 = \frac{\pi}{2r^2} \quad (1)$$

Cell Type	Service	Band	r/R (2)	# radios
MC	LTE	700 MHz	1.0	1x
SC	CBRS	3.5 GHz	0.09	200x
SC	mmWave	28 GHz	0.003	175,000x

- 100% coverage for CBRS 3.5 GHz will require 200x more small cell radios than macrocell radios. There are not enough towers.
- Therefore, small cell cost of equipment, install, real estate, power, and backhaul has to be <1% of macrocell costs. So, almost free.
- Macrocell install cost is $20K to $50K. Thus, small cell install cost has to be $100 to $250. That is the cost of a CM install. That is possible with HFC.

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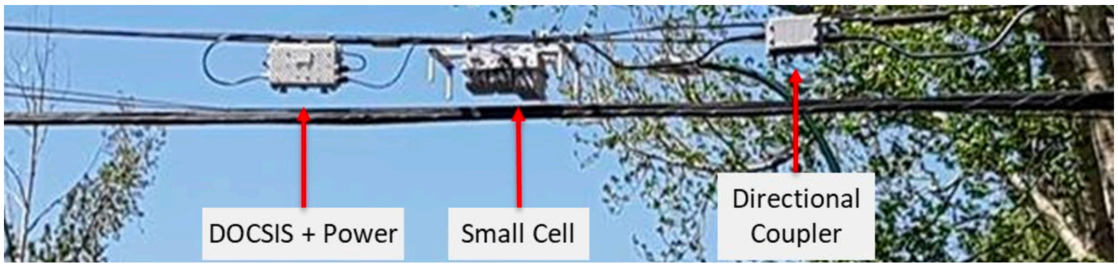
(1) John Chapman, Cisco, "*Small Cell Traffic Engineering*", SCTE 2020 WP
(2) MoffetNattanson, *Telecom Report,* Apr 2020, page 120

DOCSIS is Needed for 5G Xhaul



Actual small cell strand-mount deployment by Shaw Communications

HFC (Hybrid Fiber Coax) passes 93% of USA HHP and provides what small cells need

- Current features: Site (strand-mount or home), power, backhaul
- New features: 1588 timing (SYNC) and LLX (Low Latency Xhaul) for 1-2 ms upstream latency

Every great wireless network needs a great wireline network

- Macrocells have traditionally been on towers and backhauled by fiber
- Altice, Cox and Shaw have deployed strand-mount small cell Xhaul over DOCSIS (>20,000)
- Small cell density is > 50x compared to macrocells requiring economics of 1% to 2%

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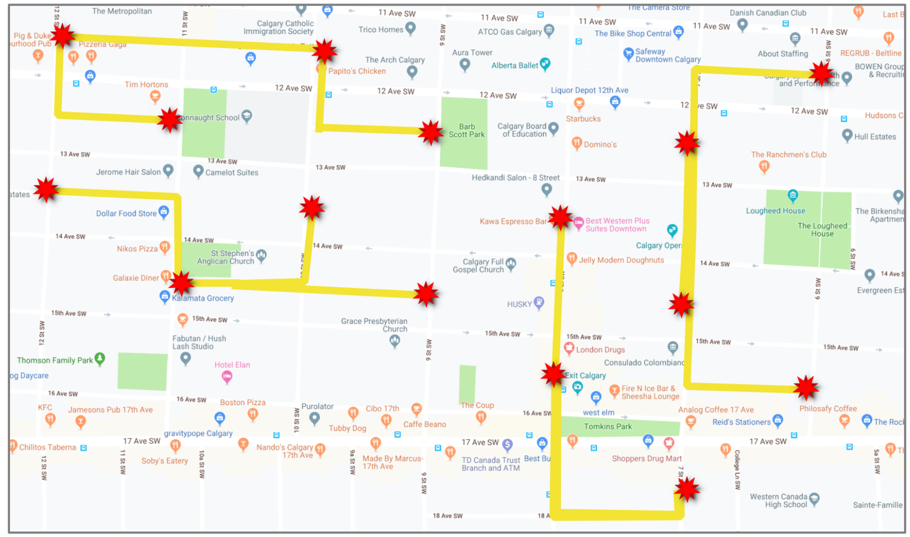
Small Cell Build – Real World Analysis from Shaw

Model of Small Cell Urban Civil Build
- time & construction costs only
- 15 small cells across 13 fiber nodes
- small cells powered from HFC plant

Fiber (in yellow):
- DWDM build to nearest fiber location
- fiber cost from node to hub not included

Coax (red star):
- coax build to nearest HFC plant
- less than 10 meters run, cut-in coupler
- no permitting/access issues
- no civil build needed



Backhaul Option	BB Fibers	Construction Cost	Time to Build
Fiber	1	$182,500	4-6 Months
Coax	0	$1,500	1 Week
SAVINGS		1% of Cost	20x Faster

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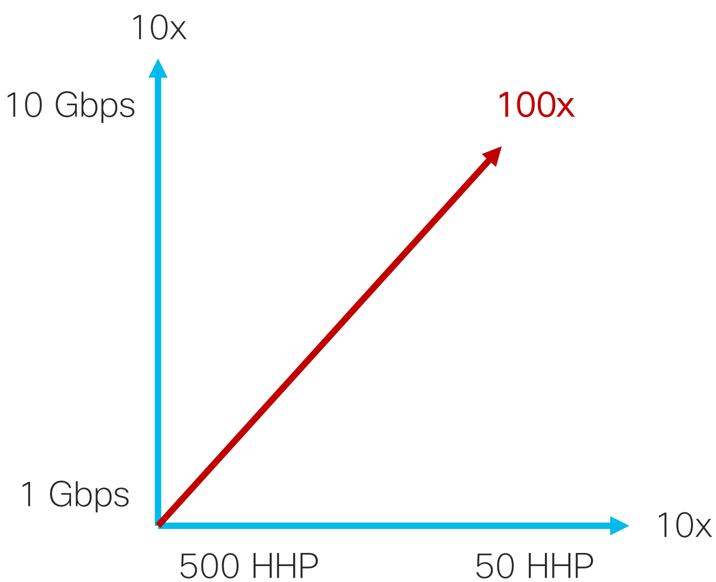
Moving Forward



DOCSIS has a growth potential of 100x in the DS and US

Spectrum Reuse/Extension:

- Downstream spectrum can go from 1 Gbps to 10 Gbps (10x)
- Upstream spectrum can go from 100 Mbps to 1.4 Gbps (14x) to 3.7 Gbps (37x)

Deep Fiber:

- Segment plant from 500 HHP N+5 to 50 HHP N+0 (10x)

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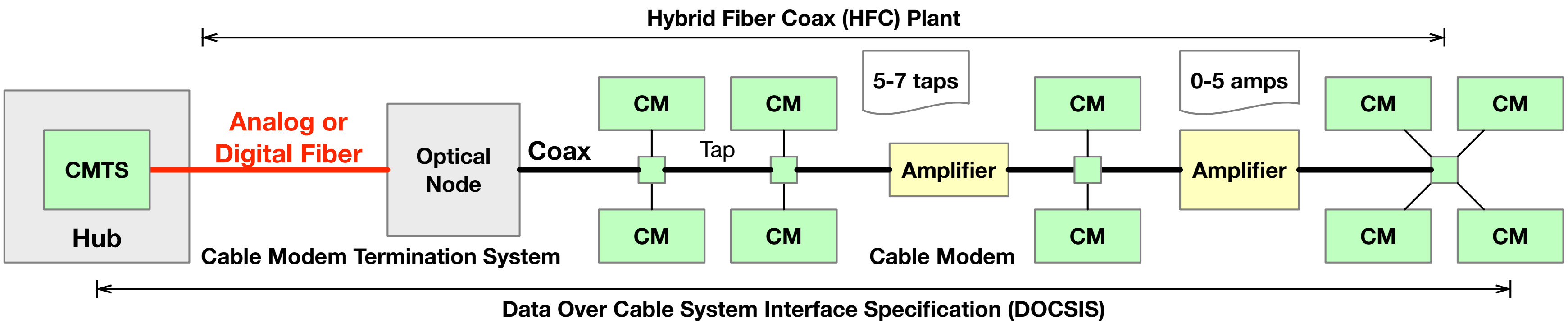
DTP – DOCSIS Time Protocol

Operation

What is DOCSIS and HFC?



HFC

- Fiber to the neighborhood, coax to the door
- Reaches 93% of American households
- Currently analog fiber, migrating to 10 GE

DOCSIS

- Data communications protocol between CMTS and CM
- Maintained at CableLabs. Six iterations since 1997. Deployed worldwide

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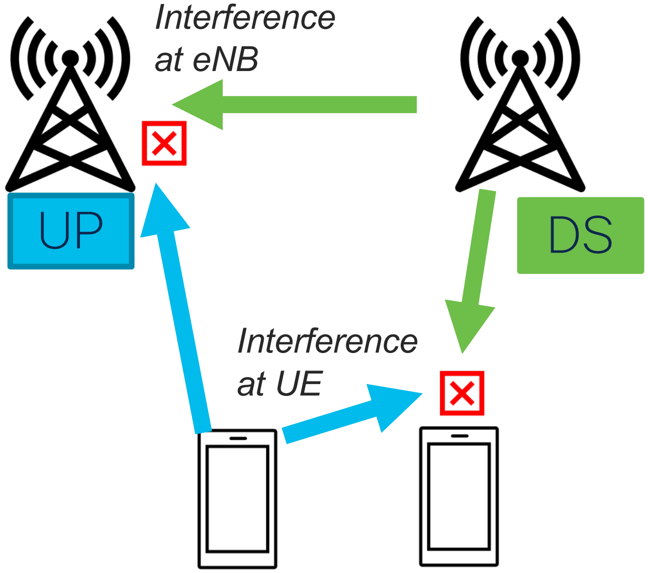
Why Do Small Cell Require Global Timing

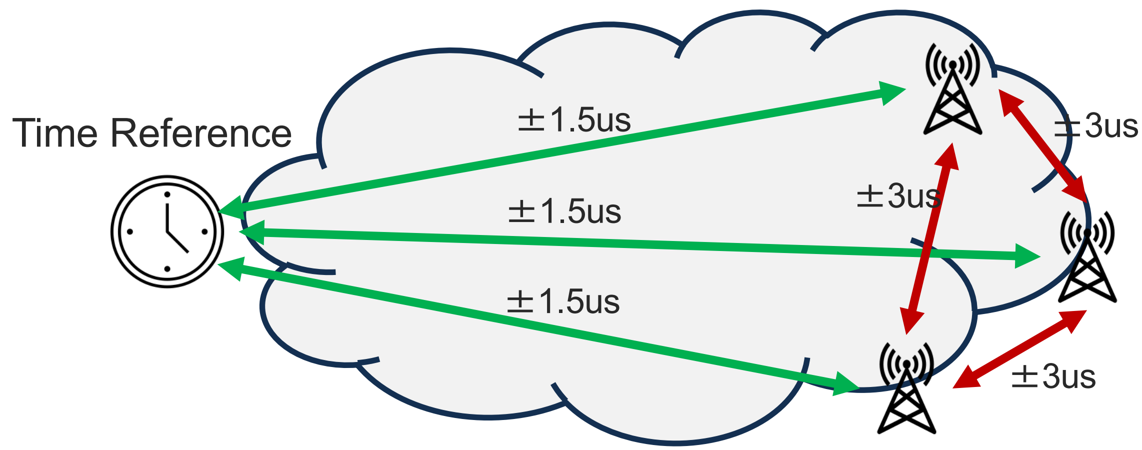
What's the problem?

- Interference at eNBs and UEs



What's the solution?

1. 3GPP: 3us between base stations
2. Radio backhaul network: ±1.5us from reference time



This is a critical concern for TDD, less so for FDD

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Introducing the DOCSIS Time Protocol (DTP)

Goals

- To provide precise frequency and time to a device that is connected to the network port of a DOCSIS CM
- Use the native properties of DOCSIS rather than explicitly design in separate 1588 clocking circuitry
- Note that PTP over the top of DOCSIS adds timing error due to upstream scheduling jitter and asymmetrical delay

Applications

- Wireless/cellular backhaul of small cells over DOCSIS
- Eliminates GPS receiver in eNB. This lowers cost and eases installation

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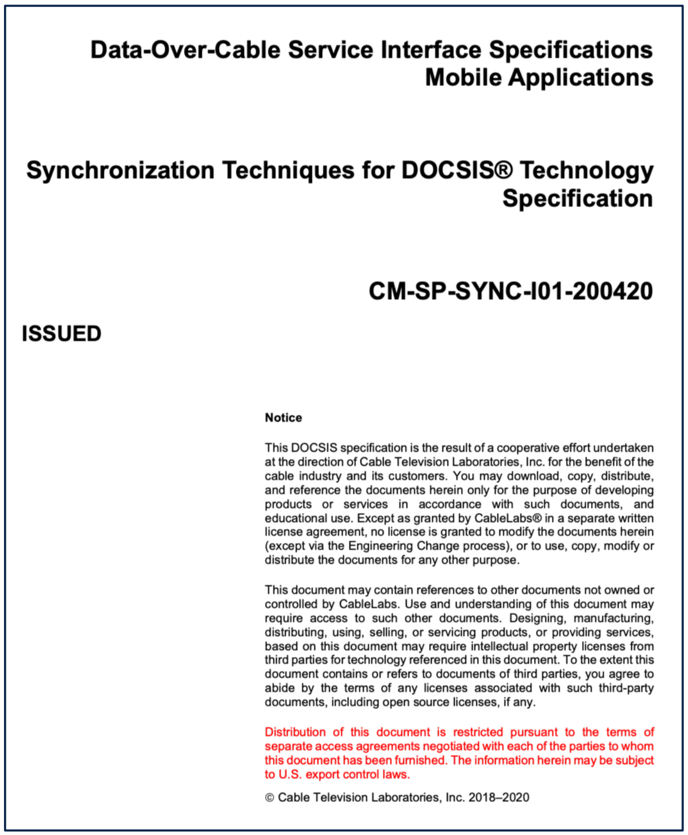
DTP Bibliography



Data-Over-Cable Service Interface Specifications
Mobile Applications

Synchronization Techniques for DOCSIS® Technology Specification

CM-SP-SYNC-I01-200420

ISSUED

Notice

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DTP was invented by John Chapman at Cisco in 2010 to allow a DOCSIS system to support hardware-based network timing using existing DOCSIS infrastructure.

- John T. Chapman, Rakesh Chopra, Laurent Montini., "The DOCSIS Timing Protocol (DTP), Generating precision timing services from a DOCSIS system," *INTX/SCTE Spring Technical Forum*, 2011. [link]
- Jennifer Andreoli-Fang, John T. Chapman, "Mobile Backhaul Synchronization Architecture," *SCTE Cable-Tec Expo Fall Technical Forum*, Denver, October, 2017. [link]
- Elias Chavarria Reyes, John T. Chapman, "How the DOCSIS Time Protocol makes the SYNC Specification Tick," *SCTE Cable-Tec Expo Fall Technical Forum*, Denver, Oct, 2020. [link]
- "DOCSIS MAC and Upper Layer Protocols Interface Specification", CM-SP-MULPI, CableLabs. [link]
- "Synchronization Techniques for DOCSIS Technology Specification," CM-SP-SYNC, CableLabs. [link]

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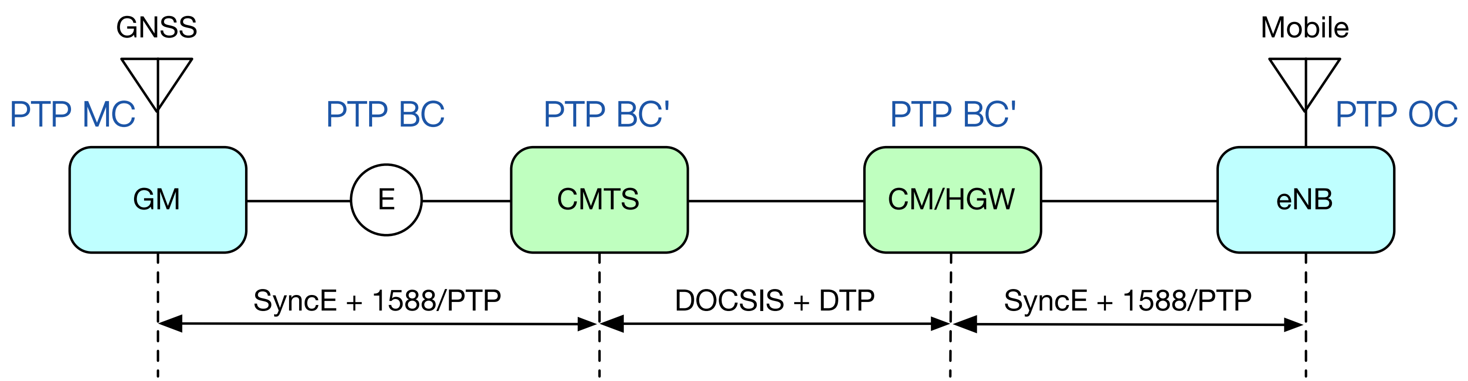
Timing Support



DOCSIS Time Protocol (DTP)

- Allows for the passing of network timing over DOCSIS 3.1 while DTP accounts for HFC plant and path asymmetry and latency
- CMTS synchronizes to PTP/SyncE and generates DTP. CM terminates DTP and regenerates PTP.

Timing & Phase

- Meets ITU-T requirements for 4G-LTE-TDD & 5G of ±1.5 µsec end-to-end
- Time error (TE) budget includes DOCSIS and nodes and amplifiers from the HFC plant

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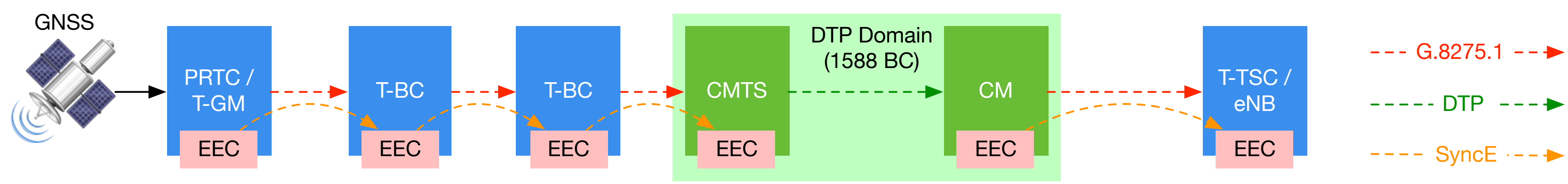
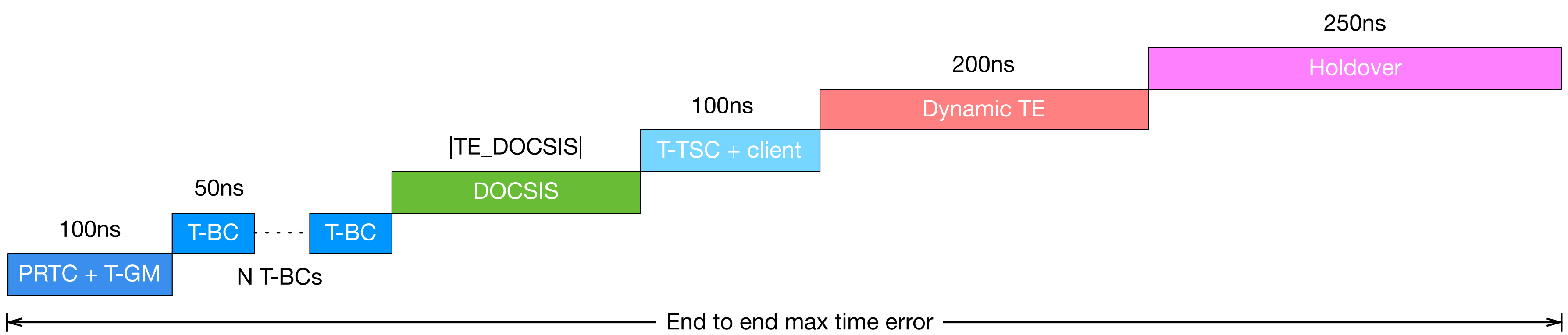
Time Error Budgeting for MBH over DOCSIS





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Time Error Budget for HFC

Budget Component	ITU-T Reference	I-CMTS			DAA		
		n	@	TE	n	@	TE
PRTC *(Class A is 100 ns, Class B is 40 ns, ePRTC is 30 ns)*	100	Class A		100	Class A		100
Network holdover and PTP rearrangements	NA or 400			200			200
Network dynamic TE and SyncE rearrangements	200 for 10 BC			200			200
T-BC *(Class A is 50 ns, Class B is 20 ns)*	500 for 10 BC	2	50	100	4	50	200
Link asymmetry	250 for 10 BC			50			50
Ethernet and Dynamic Aspects of Ethernet TE Budget	**1050**			**650**			**750**
CMTS *(Class A is 200 ns, Class B is 100 ns)*		Class A		200	Class A		200
DTP				50			50
HFC path				50			10
HFC node				50			10
HFC amp/LE		N+5	10	50	N+3	10	30
CM *(Class A is 250 ns, Class B is 100 ns)*		Class A		250	Class A		250
DOCSIS Network TE Budget				**650**			**550**
Rearrangements and short holdover in the end application	250 or 0			0			0
Base station slave or intra-site distribution	50	Class A		50	Class A		50
Base station RF interface	150			150			150
Base Station Network TE Budget	**450**			**200**			**200**
Total TE Budget	**1500**			**1500**			**1500**

The TE budget for DOCSIS was taken from the Ethernet and base station budgets.

- The ITU-T +/- 1500 ns TE budget for mobile has been re-distributed across the combined Ethernet network, the HFC plant, and the end network with the eNB.
- Link asymmetry and hold-over assumptions were changed.
- Timing Error (TE) budgets were assigned to the I-CMTS (or DAA/RPD), Nodes, Amps and the CM along with Class A and B options.

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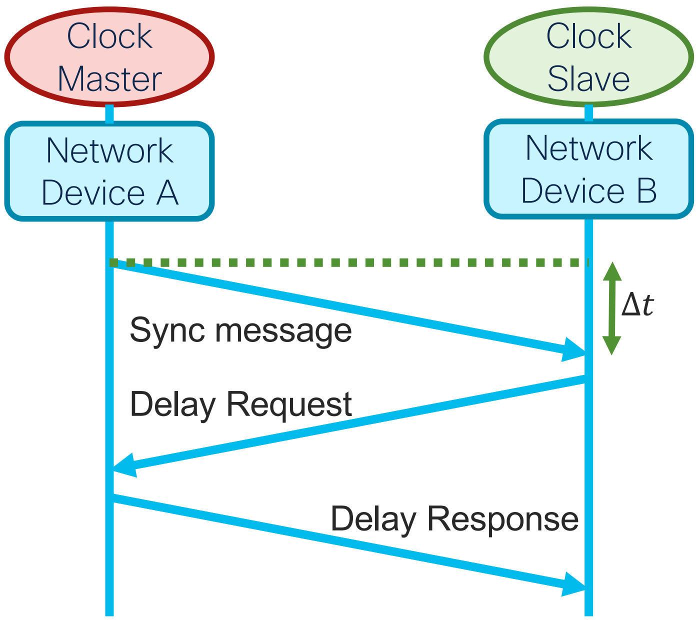
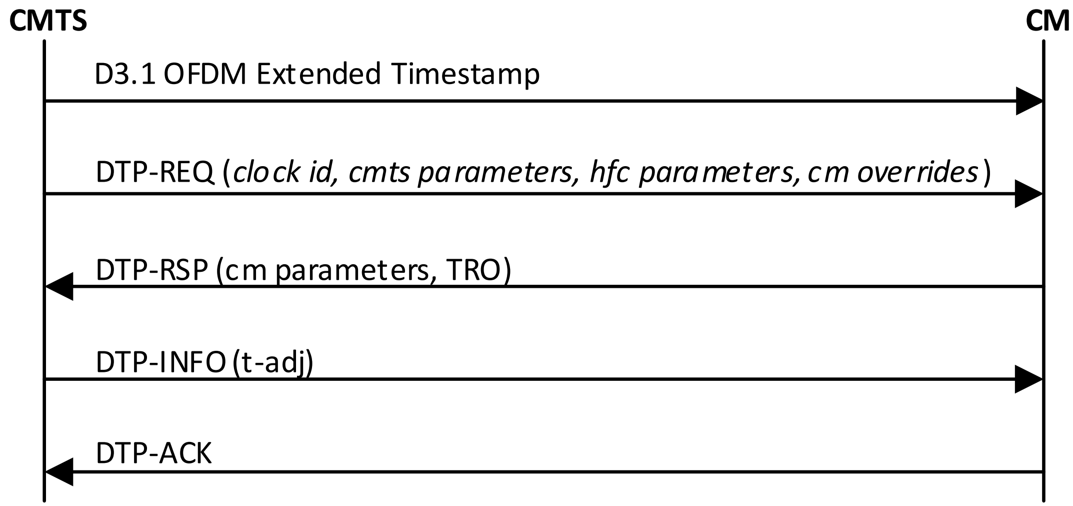
Time and Delay for PTP and DTP





PTP sync message replaced by DOCSIS timestamp

PTP delay request/response messages are replaced with DTP true ranging offset (TRO)

PTP announce message sent over DOCSIS

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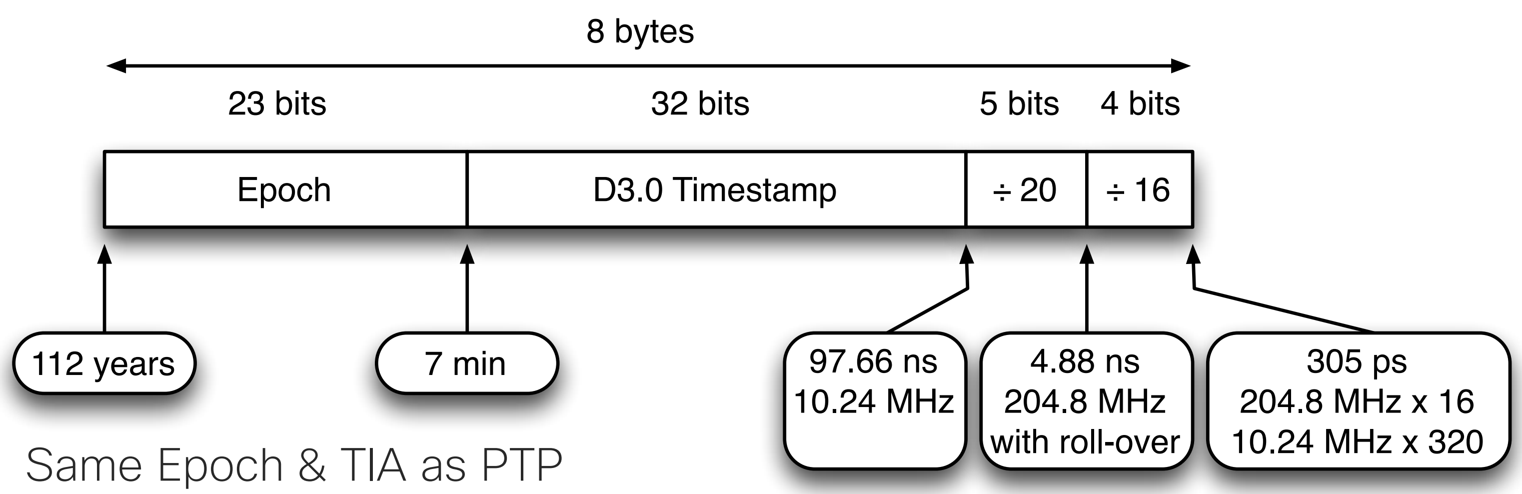
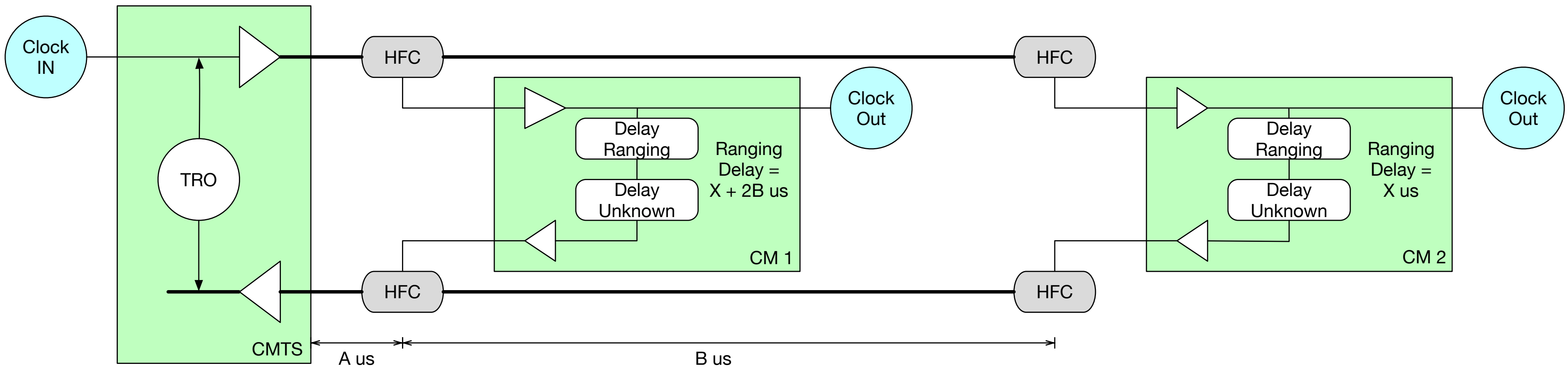
DOCSIS 3.1 Timestamp



Comparison	Size	Precision	Max Time
DOCSIS 3.0	32 bits	97.7 ns	7 min
DOCSIS 3.1	64 bits	305 ps	112 years
IEEE-1588	64 bits	1 ns	584 years
NTPv1	64 bits	233 ps	136 years
NTPv4	128 bits	500 atto-seconds	Universe start to end

True Ranging Offset (TRO)



- DOCSIS ranging negotiates a unique delay for each CM so that their upstream transmission bursts arrive at the CMTS at the correct scheduled time.
- *From the results of the ranging process, a round trip time can be established.* This replaces the PTP delay request/response algorithm
  - The difference between a 0 mile CM (X + 2B μs) and a 100 mile CM (X μs) is the RTT of the plant.
- This is known as the True Ranging Offset. It is derived through a specific algorithm.

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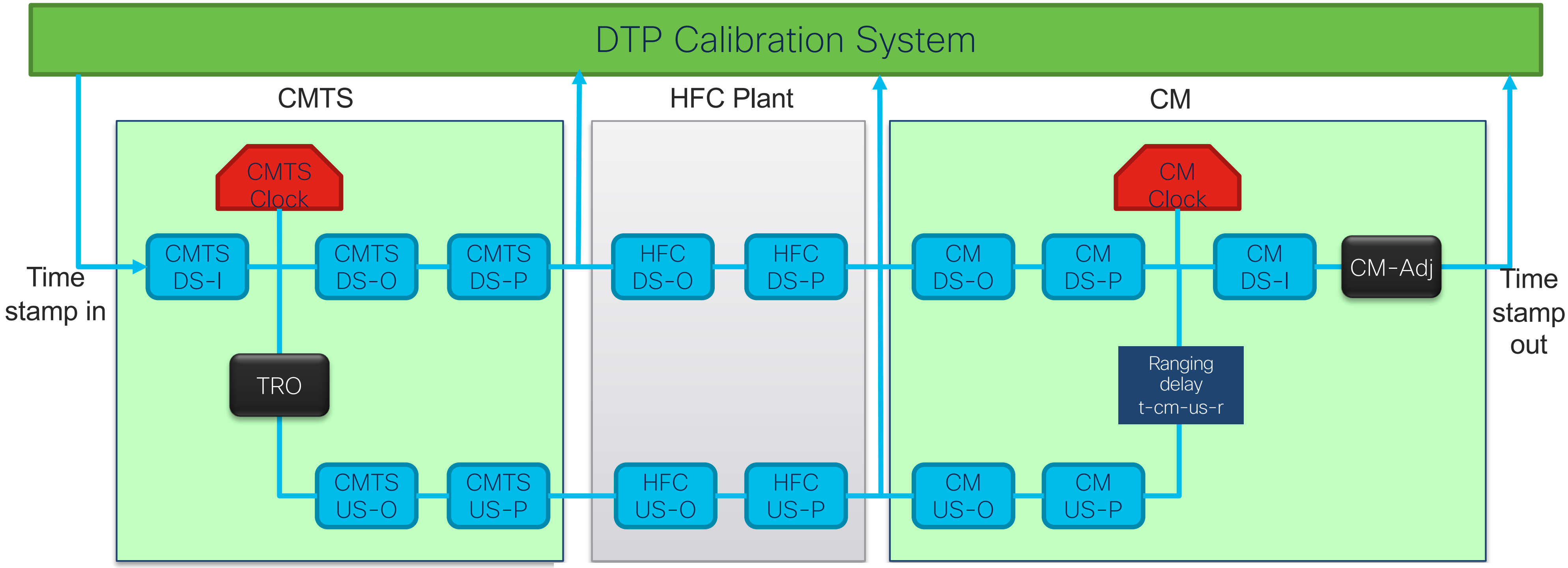
DTP Timing Model



Baseline equations without CMTS/CM pairs

$$t\text{-}hfc\text{-}ds\text{-}p = (t\text{-}tro - t\text{-}cmts\text{-}ds\text{-}o - t\text{-}cmts\text{-}ds\text{-}p - t\text{-}hfc\text{-}ds\text{-}o - t\text{-}cm\text{-}d\text{-}o - t\text{-}cm\text{-}ds\text{-}p - t\text{-}cm\text{-}us\text{-}o - t\text{-}cm\text{-}us\text{-}p - t\text{-}hfc\text{-}us\text{-}o - t\text{-}cmts\text{-}us\text{-}o - t\text{-}cmts\text{-}us\text{-}p) / 2$$

$$t\text{-}cm\text{-}adj = t\text{-}cmts\text{-}ds\text{-}i + t\text{-}cmts\text{-}ds\text{-}o + t\text{-}cmts\text{-}ds\text{-}p + t\text{-}hfc\text{-}ds\text{-}o + t\text{-}hfc\text{-}ds\text{-}p + t\text{-}cm\text{-}d\text{-}o + t\text{-}cm\text{-}ds\text{-}p + t\text{-}cm\text{-}ds\text{-}i$$

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True Ranging Offset

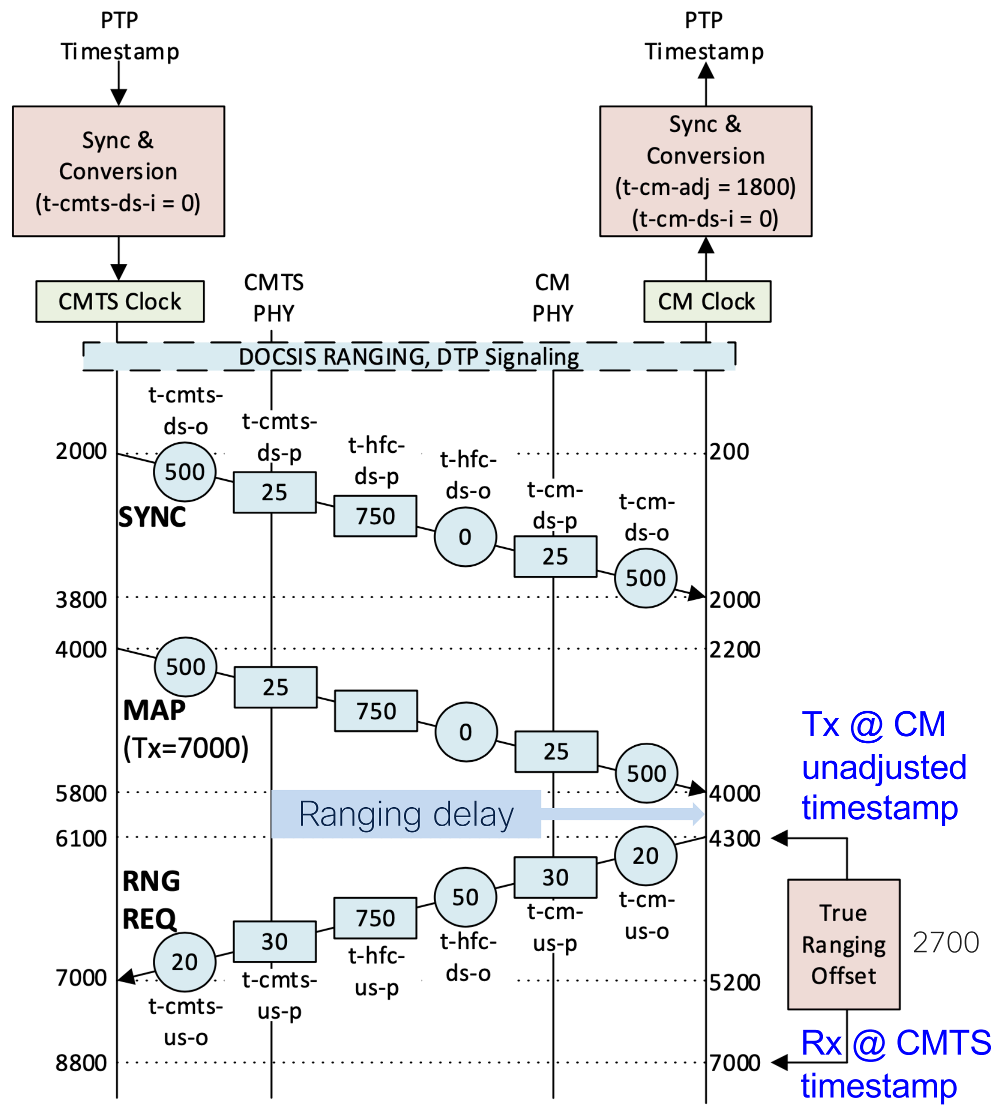
The TRO is measured at the CM between the following two reference points:

- The <u>unadjusted CM timestamp</u> when the upstream burst begins
- The <u>CMTS timestamp</u> for the scheduled arrival time of that upstream burst

This indirectly provides the <u>round-trip delay</u> of the network segment

This is a technique that is unique to DTP

Then derive DS one-way time delay RTT and add to CM clock to get PTP clock.



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Basic TRO Example

TRO = total round-trip delay
TRO = CMTS + CM + HFC delays
TRO – CMTS – CM = HFC delay

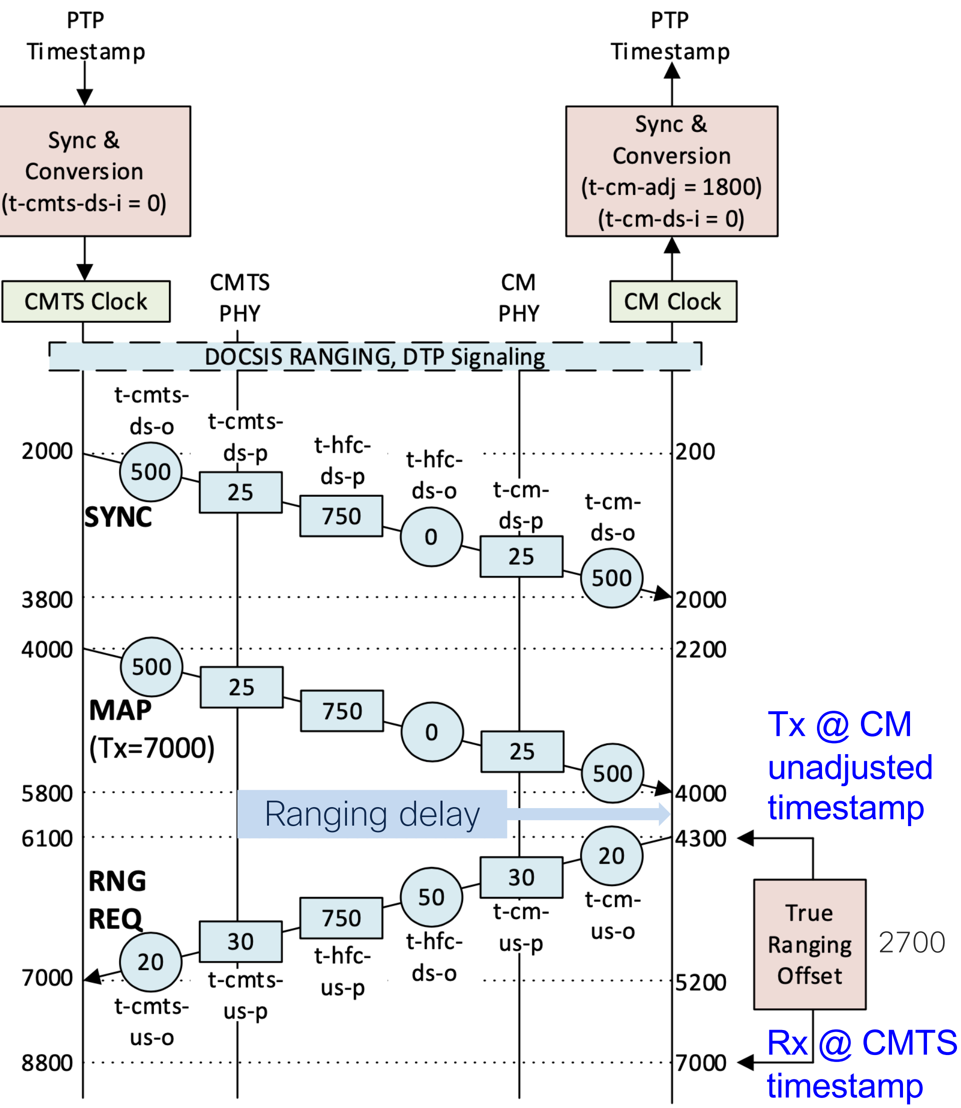
2700 – (525+50) – (525+50) = 1550

DS HFC Plant Latency
= 1550 / 2 = 750 *(note 1)*

Total DS Latency
= 500+25+750+25+500 = 1800

Corrected CM Timestamp
= 7000 + 1800 = 8800

Note 1: adjustments for asymmetry are applied here



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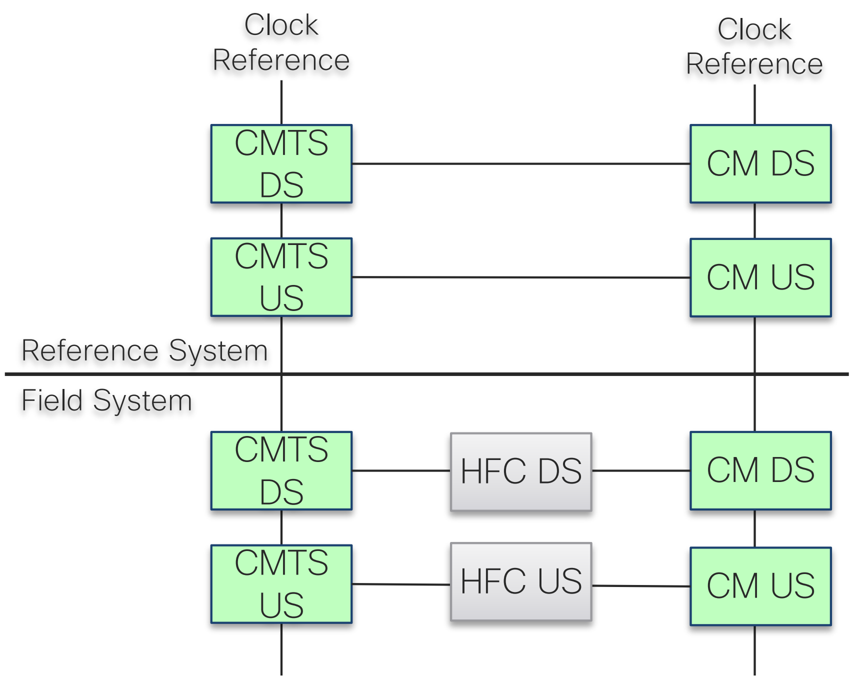
Real World Considerations

- Decent TE budgets allows for decent results, but smart calibration will result in better than spec results
- However, network elements may not be able to calibrated separately due to lack of media-specific test equipment
- Alternatively, CMTS/CM can be calibrated in pairs by comparing a zero mile length plant to a deployed plant
- The latest lab results can be published on a website



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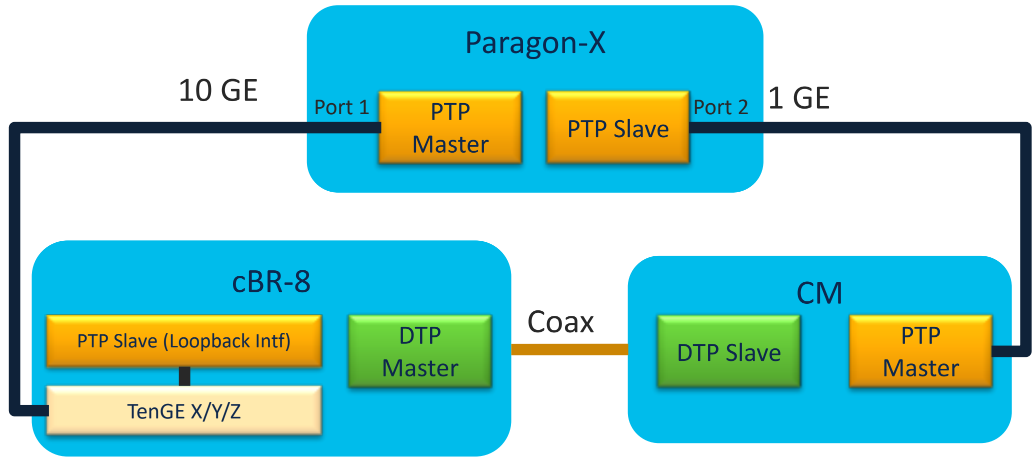
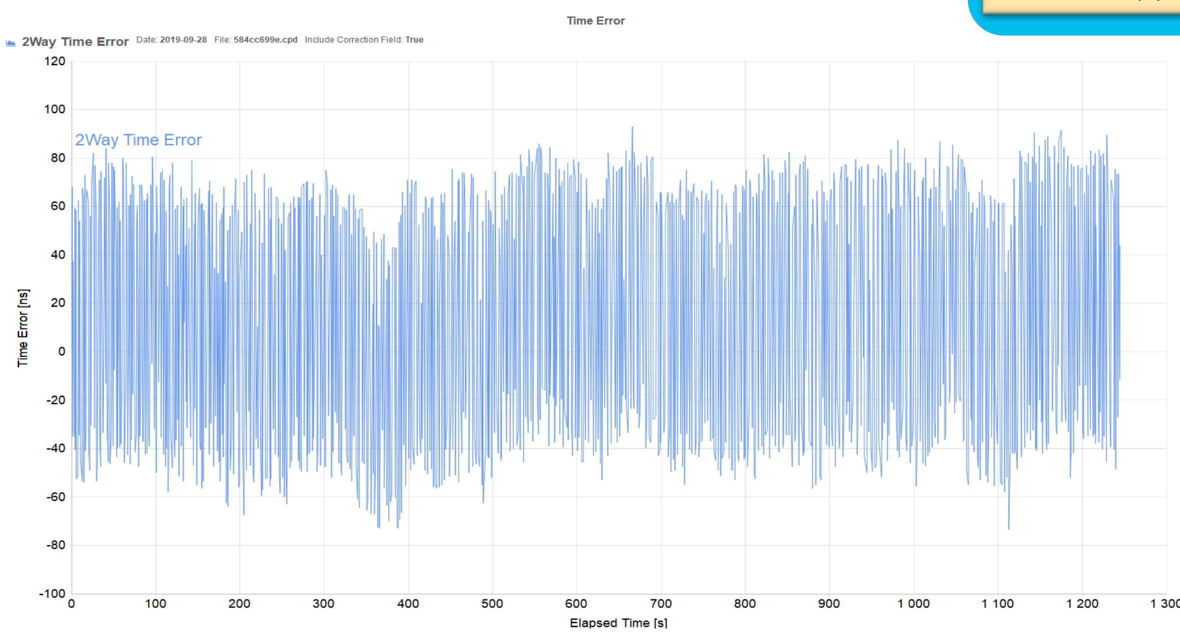
DTP Test Results

- Cisco cBR-8 CMTS
- Intel reference design CM



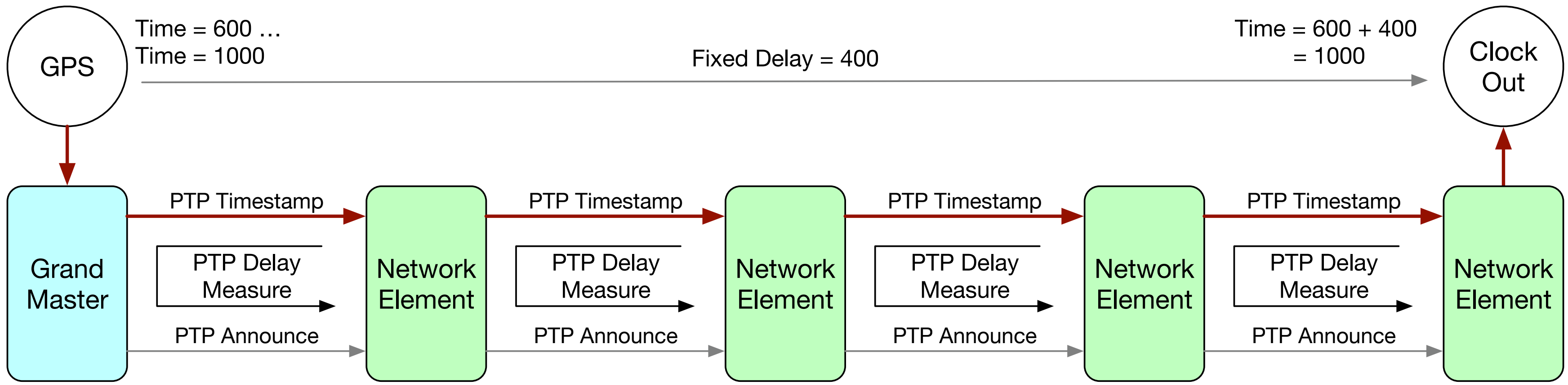


cTE = ± 80ns for DOCSIS link

DTP – DOCSIS Time Protocol

Summary

IEEE 1588/PTP In a Nutshell



1. Receive time centrally from GPS. Send it as a timestamp across the network. Design hardware to make network elements appear as a fixed delay
2. Measure the round delay and divide by two for one-way delay
3. Add delay (400) to previously received timestamp (600) to get global time (1000)

The principal can be learned in 5 minutes, but it seems to take a lifetime to get it right

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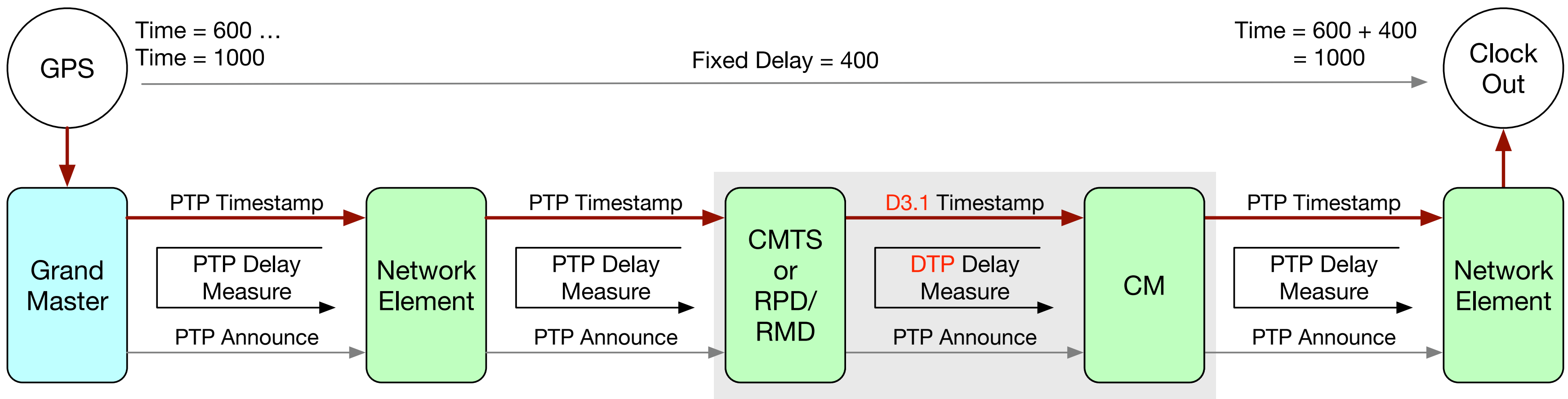
DTP In a Nutshell



- Same as PTP except on the DOCSIS link, DOCSIS provides the timestamp and the equivalent of two-way delay measurements derived from ranging measurements
- CMTS is already synchronized and timestamp has Epoch built in
- PTP Announce is sent as a L3 message over DOCSIS

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DTP Recap

Rather than run NTP or PTP over-the-top, the DOCSIS system can be used as-is to generate these timing protocols at the CM with a very high degree of precision

- CMTS synchronizes DOCSIS to a PTP/SyncE
- DOCSIS provides a stable clock and a timestamp. DTP manages latency and asymmetry for DOCSIS
- CM regenerates PTP/SyncE using DOCSIS timing

Accuracy is dependent upon accurate modeling and calibration of CMTS, CM, and HFC plant

DOCSIS can provide accurate network timing for MBH

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